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SURVEILLANCE AND CONTROL OF LAKE  
EUTROPHICATION IN THE GREAT LAKES BASIN  
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# APPLICATION OF LANDSAT TO THE SURVEILLANCE AND CONTROL OF LAKE EUTROPHICATION IN THE GREAT LAKES BASIN

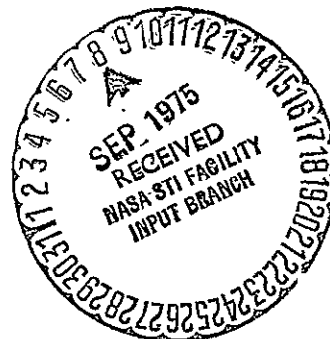
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16. Abstract  This paper reports on the results achieved during the second three months to establish cost benefits of LANDSAT for the surveillance and control of lake eutrophication. This goal is being accomplished by producing LANDSAT products for an EPA modeling study of Saginaw Bay and inland lake surveys by the Michigan and Wisconsin DNR's. These user agencies are, in-turn, providing detailed ground truth on water quality and are participating in studies and evaluations to determine the cost benefits of LANDSAT.			
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## PREFACE

### Program Objectives

The overall objective of this investigation is to establish the cost benefits of using LANDSAT on an operational basis in the surveillance and control of lake eutrophication. This objective is accomplished by supporting, with LANDSAT data products, bona fide users who will evaluate the data's usefulness to on-going programs concerned with the classification and control of lake eutrophication. The products supplied to the users will be made as applicable as possible to their data needs. The following therefore, are specific objectives to be addressed:

1. To identify the data requirements of the users and to relate these to LANDSAT data with respect to land-water categories, detail, scale, and frequency.
2. To identify water quality parameters which relate directly to eutrophication and to determine quantitative levels of these parameters by which lakes may be categorized as to trophic state.
3. To identify land-use patterns which relate to trophic state.
4. To develop and apply LANDSAT data imaging and interpretation techniques to categorize water and land-use features identified in order to produce information products of value to users.

### Scope of Work

This investigation is supplying LANDSAT-derived information products to three federal and state agencies which are involved in the planning and management of lakes and watershed land use in the Great Lakes basin. Support will be provided to the Environmental Protection Agency water quality survey and modeling study of lake eutrophication in Saginaw Bay; the State of Michigan Department of Natural Resources Survey of inland lakes and watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution due to land-use practices; and the State of Wisconsin Department of Natural Resources lake survey to determine eutrophication status, causes, effects, and control treatments. For each of these three programs, this investigation will analyze and interpret LANDSAT data to provide the three user agencies with land-use and lake water quality information about their specific test areas. The usefulness of

LANDSAT data to each type of study and the cost benefits of its use over alternative data collection systems will be evaluated.

### Conclusions

Earlier results of the Saginaw Bay study showed good agreement between the distribution of water masses categorized from LANDSAT data and Secchi depths (water clarity) measured within the water masses. Better correlations are expected, however, with current measurements of suspended solids and associated parameters (algal counts, total suspended carbon). Further data processing will proceed when the best 1975 scenes are identified and the CCT is available.

Inland lakes in two areas of Wisconsin have been successfully classified into general water types (algal, clear, tannin and silty) and bottom effects, and were mapped in categorized color imagery.

Certain test lakes were also characterized by LANDSAT spectral signatures adjusted to reduce atmospheric effects. A window in late summer was identified as the preferred time to monitor trophic levels in lakes; primary production levels in these lakes generally stabilize during late August to early September. Bottom effects on lake reflectance were best identified in late spring when the water was clearest.

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## 1. REVIEW OF PROGRAM AND DISCUSSION OF RESULTS

This section reports on the work accomplished and results achieved during the second three months of a program to establish the cost benefits of LANDSAT for the surveillance and control of lake eutrophication. To accomplish this goal, LANDSAT data products are being generated to support the Environmental Protection Agency (EPA) modeling study of lake eutrophication in Saginaw Bay; the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments.

These user agencies are providing, at no cost to NASA, user needs which include desired data formats, data timeline requirements (i. e., how fast data are needed and how long it maintains its value before update is needed), and data accuracy requirements (i. e., geometric and classification accuracy). These agencies are also providing detailed ground truth on water quality and watershed land use in conjunction with LANDSAT overflights and are participating in studies and evaluations to determine the usefulness and cost benefits of the LANDSAT data products.

The remainder of this section reports on the work accomplished and results achieved to support the on-going water quality programs of the three user agencies.

### 1.1 SUPPORT FOR THE EPA STUDY OF WATER QUALITY IN SAGINAW BAY

As noted in the previous report, the EPA is sponsoring a 36-month study of water quality in Saginaw Bay, which will terminate in June 1976. Important goals of this study are to describe, on a seasonal basis, the circulation and water masses in Saginaw Bay; to monitor inputs of nutrients from its watershed; and to develop and evaluate models for predicting water quality in the bays as a function of various control strategies.

Currently, EPA is acquiring water quality data on Saginaw Bay through a study being conducted by Cranbrook Institute of Science under the direction of Dr. V. Elliott Smith (LANDSAT co-investigator). During April 1974 - February 1975, 59 bay stations were sampled on a schedule that coincided with LANDSAT-1 overflights. Since April 1975, 37 of the same stations have been sampled on the LANDSAT-2 schedule. Field and laboratory measurements of some 30 water quality parameters will continue through November 1975.

As reported last quarter, a preliminary mapping of water masses in the bay was carried out using LANDSAT and ground data for June 3, 1974. A publication was attached which described this experiment in which water

classification was based on measured values of Secchi depth (water transparency). We found fairly good agreement between measured Secchi depths and those "predicted" from the processed data at other stations which were not included in the computer training process. However, since Secchi depth measurements are only approximations of water turbidity, we are currently examining the relationship of Secchi depth to other physical and chemical parameters in Saginaw Bay. This is being done by a series of multiple regression analyses of all of the 1974 Saginaw Bay data. Spatial and temporal considerations will be applied in the analysis of these relationships.

Although some additional LANDSAT coverage of the bay during 1974 is available, no other data have been processed. An important reason is that data on suspended solids were lacking in 1974, but have been collected since April 1975. It seems likely that these measurements will provide a better basis than Secchi depth for classifying water turbidity using LANDSAT data. In other words, the concentration and color of suspended solids should correlate well with LANDSAT reflectance measurements and ratios. Several clear scenes of the bay (that coincide with sampling) have been recorded this year, but the corresponding tapes (CCT) are not yet available. Further mapping of water masses will be tried when the tapes are on hand. A particular scene of interest will be that recorded on last July 13. At that time the lower part of Saginaw Bay was covered with a surface film of blue-green algae in addition to high turbidity below. It is likely that this will boost reflectance in bands 6 and 7 and permit accurate mapping of the surface scum.

As part of the Cranbrook-EPA study, a unique scanning spectroradiometer is being developed (at no cost to NASA). This will be used in the field to record downwelling and upwelling irradiance over the visible - near IR spectrum (400-1100 um). The fast rate of scan (ca. 1 second) and digital recording of the data will allow the radiometer to be used aboard ship for characterizing water color and deriving atmospheric corrections for LANDSAT data. One goal of this work is to determine relationships between water quality factors, such as suspended solids, and absolute (%) reflectance recorded by LANDSAT.

Ultimately in this program, the results of water mass mapping from LANDSAT data will be compared with the output of models which simulate the distribution of water quality factors in Saginaw Bay. The models will necessarily represent the bay as a series of compartments or segments within which water quality is assumed to be uniform. This, for purposes of comparison it will be necessary to tabulate water categories (in classified LANDSAT data) over corresponding portions of the bay. A new program developed at Bendix allows the operator to quickly specify a part of the classified data displayed on the CRT using the cursor. He then limits the automatic tabulation

of data to that area alone. In addition, Bendix has recently installed a new drum film recorder for direct production of classified imagery at a scale of 1:250,000 or larger.

## 1.2 SUPPORT FOR MICHIGAN'S SURVEY OF INLAND LAKES AND WATERSHEDS

To review the State of Michigan program, the DNR is committed, under the State Federal Water Pollution Control Act (Act 92-5000), to a state-wide survey of public lakes and their watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution resulting from land-use development in the watershed. A requirement of the DNR program, as well as programs of other governmental agencies concerned with the maintenance and control of water quality, is to develop a knowledge of the interrelationships between the water quality parameters (turbidities, chlorophyll concentrations, etc.) and watershed land-use parameters (land-use categories and coverage).

To obtain the needed information, the Michigan DNR has selected test lakes whose watersheds contain various levels of urbanization. LANDSAT is to be used to inventory land use within these watersheds. The land-use data mapped by LANDSAT will be correlated with lake water quality measurements obtained by the DNR concurrent with the LANDSAT inventory. Possible correlations between LANDSAT measurements and water quality parameters will also be investigated.

Recently, the Michigan DNR requested an extension of their test site to include a total of 19 inland lakes in southern Michigan, which represent a broad spectrum of water quality and trophic conditions. NASA approved this request on July 23, 1975. Figure 1 identifies the counties where these lakes are located. Table 1 lists some physiographic and quality data for these lakes. In all of these lakes, water quality studies are underway or will be initiated to coincide with one or more LANDSAT passes during 1975. Intensive ground surveys are in progress on 12 of these lakes in the following counties: Jackson, Ingham, Genesee, Kent, Montcalm, Clare, Cheboygan and Emmett. These surveys include measurements of suspended solids, turbidity, transparency, chlorophylls, algal flora and water chemistry variables. Land use and cover factors which may impact on water quality are also being studied within these watersheds.

A number of different land use/cover categories are being considered by the DNR as having a varying influence on water quality in the test lakes. These include the following: urban (heavy industrial/commercial; high and low density suburban), extractive (bare earth), grasslands (native and tended), croplands, wetlands, forest (evergreen and deciduous) and water (several types). Bendix has determined in earlier LANDSAT (ERTS-1) studies



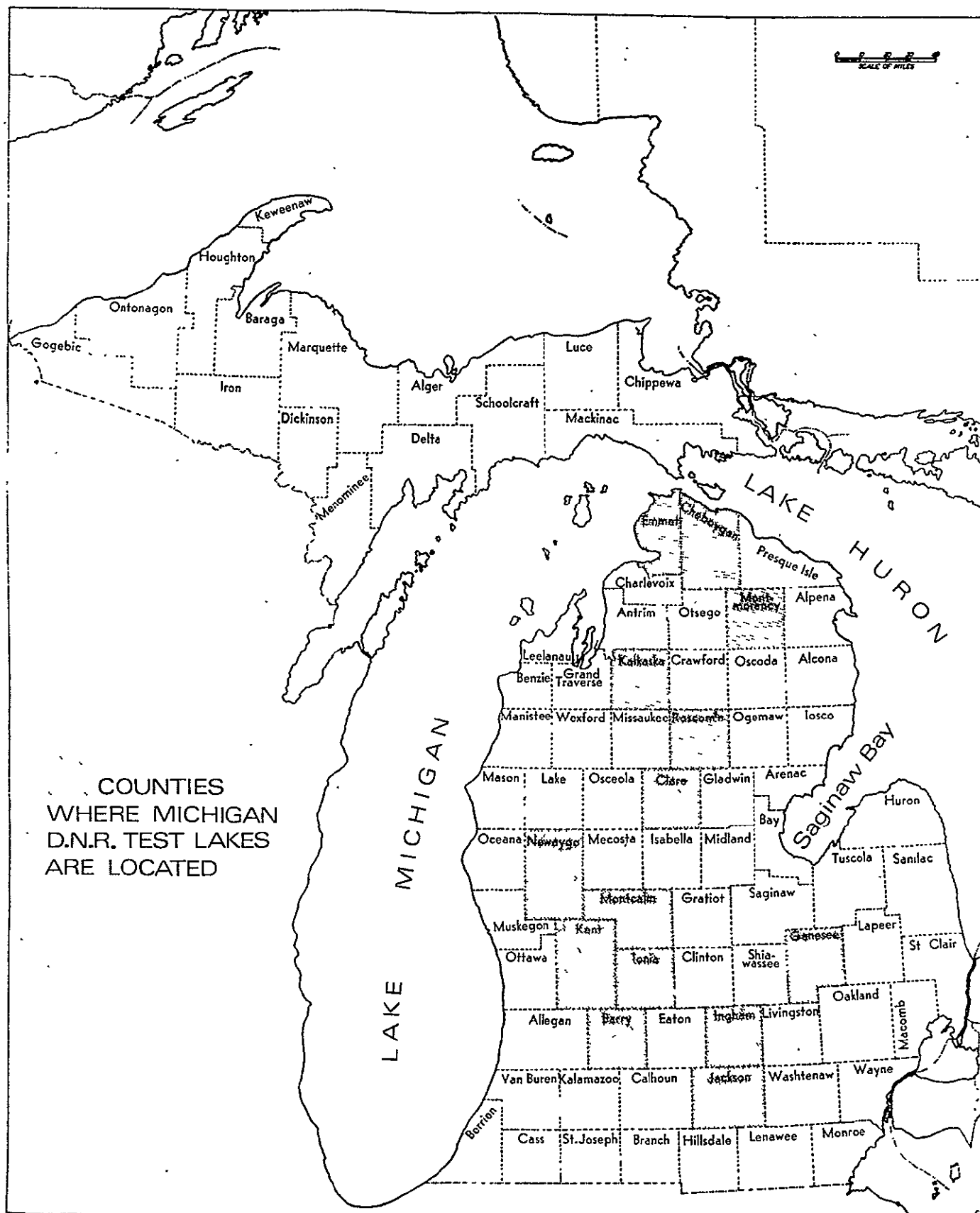


Figure 1. Location of Michigan test areas: Saginaw Bay and inland lakes.

Lake	County	Lake Area		Watershed Area		Shore Length		Lake: Watershed Area Ratio	Approx. Trophic Level
		Acres	KM <sup>2</sup>	Acres	KM <sup>2</sup>	Miles	KM		
Pleasant*	Jackson	247	1.00	519	2.10	279	4.49	1:2.10	Mesotrophic
Lansing*	Ingham	454	1.84	2081	8.42	365	588	1:4.58	Eutrophic
Silver*	Genesee	252	1.02	2050	8.30	5.01	8.07	1:8.13	--
Jordan	Ionia & Barry	372	1.51	3626	14.68	4.48	7.20	1:9.73	Hypereutrophic
Long	Ionia	358	1.45	373	1.51	3.60	5.80	1:1.04	Mesotrophic
Reeds*	Kent	267	1.08	1811	7.33	3.27	5.26	1:6.76	Mesotrophic
Townline*	Mortcalm	292	1.18	1770	7.16	5.02	8.08	1:6.07	Mesotrophic
Fremont	Newaygo	802	3.25	3830	15.50	5.44	8.75	1:4.77	Hypereutrophic
Budd*	Clare	155	.63	864	3.49	4.15	6.68	1:5.56	Mesotrophic
Houghton	Roscommon	19,646	79.51	31361	126.92	30.09	48.43	1:1.60	Eutrophic
Higgins	Roscommon	10,300	41.68	21953	88.84	20.78	33.44	1:2.13	Oligotrophic
Bit Twin	Kalkaska	220	.89	1649	6.67	2.51	4.03	1:7.51	Oligotrophic
Clear	Montmorency	145	.59	779	3.15	2.11	3.40	1:5.37	--
Munro*	Cheboygan	686	2.78	2285	9.25	4.46	7.20	1:3.33	Eutrophic
Long*	Cheboygan	395	1.60	1028	4.16	5.37	8.66	1:2.60	Mesotrophic
Devercaux*	Cheboygan	35	.14	2492	10.09	.91	1.47	1:72.07	Mesotrophic
Wildwood*	Cheboygan	221	.90	2167	8.77	5.78	9.32	1:9.79	Hypereutrophic
Silver*	Cheboygan	76	.31	1292	5.23	.62	1.00	1:16.98	Oligotrophic
Larks*	Emmett	598	2.42	1020	4.13	3.88	6.26	1:1.71	Mesotrophic

(\*Indicates intensive ground surveys underway)

Table 1. Physiographic data on Michigan Department of Natural Resources (DNR) test lakes

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that all of these categories can be classified and mapped successfully using the satellite. Ultimately, the DNR hopes to develop an expression for the various potentials of these categories of land to discharge nutrients to lakes. Their goal is to predict the capacity of individual lakes to maintain acceptable levels of water quality while their watersheds undergo various types and degrees of development.

Twelve of the test lakes were already under study by the DNR and the University of Michigan during 1974 (Table 1), but unfortunately, were not sampled coincidentally with any clear LANDSAT (ERTS-1) passes. Consequently, a special effort is being made this August and September to accomplish this, with additional aircraft M<sup>2</sup>S coverage provided by NASA on the same day (see Section 8, Aircraft Data).

### 1.3 SUPPORT FOR WISCONSIN'S SURVEY OF INLAND LAKES

As noted earlier, the Wisconsin DNR is also attempting to develop a method of lake classification by trophic level, as required by Section 314 of the Federal Water Pollution Control Act Amendments (1972). Accordingly, the Wisconsin DNR is evaluating the utility of LANDSAT data products and the results of related investigations underway in Wisconsin.

Such an investigation, being conducted on behalf of the DNR by Dr. James P. Scherz (University of Wisconsin), is described as a progress report in Appendix A. Results to date of that study show that lakes of the Madison and Spooner area of Wisconsin can be classified by LANDSAT data processing into types characterized by varying amounts of suspended particles (algae and silt), colored solutes (tannins) and bottom reflectance. Processing of two LANDSAT-1 scenes (1756-16061, August 18, 1974 and 1020-16755, August 12, 1974) were conducted at Bendix using the M-DAS system. Previous studies of these lakes indicate that algal and plant production are most stable and best indicate trophic status during late summer (August - September). Bottom effects on reflectance are best evaluated when water is clearest during late May.

## 2. SIGNIFICANT RESULTS

By use of distilled water samples in the laboratory, and very clear lakes in the field, a technique has been developed where the atmosphere and surface noise effects on LANDSAT signals from water bodies can be removed. The residual signal dependent only on the material in the water was used as a basis for computer categorization of lakes by type and concentration of suspended material. Several hundred lakes in the Madison and Spooner, Wisconsin area were categorized by computer techniques for tannin or non-tannin waters and for the degree of algae, silt, weeds, and bottom effects present. When the lakes are categorized as having living algae or weeds, their concentration is related to the enrichment or eutrophication of the lake.

## 3. PROBLEMS

No problems are impeding this investigation.

## 4. RECOMMENDATIONS

None

## 5. PUBLICATIONS

None

## 6. FUNDS EXPENDED

Total expenditures through 11 August of 1975 are \$37,391.

## 7. DATA USE

A tabulation showing the total value of the data allowed and received through 30 July 1975 follows:

Value of Data Allowed	Value of Data Ordered	Value of Data Received
\$5,550	\$400	\$260

## 8. AIRCRAFT DATA

By prior arrangement with NASA Johnson Space Center in Houston, supportive M<sup>2</sup>S and photographic coverage of the test areas in Michigan (Figure 2) was scheduled for one of the following periods: July 31 - August 1, August 18-19 and September 5-6, 1975. The flight on the first date option was cancelled due to engine trouble with the aircraft. On August 18 Saginaw Bay and some of the inland lakes were flown with fair to good weather conditions. Ground truth on Saginaw Bay and the DNR test lakes was collected by survey teams on August 18 and 19. Some flight lines (7, 8, 9, 10, 11, 13) are now scheduled to be re-flown during September 5-6. All of the date options above correspond with LANDSAT-2 coverage of these areas.



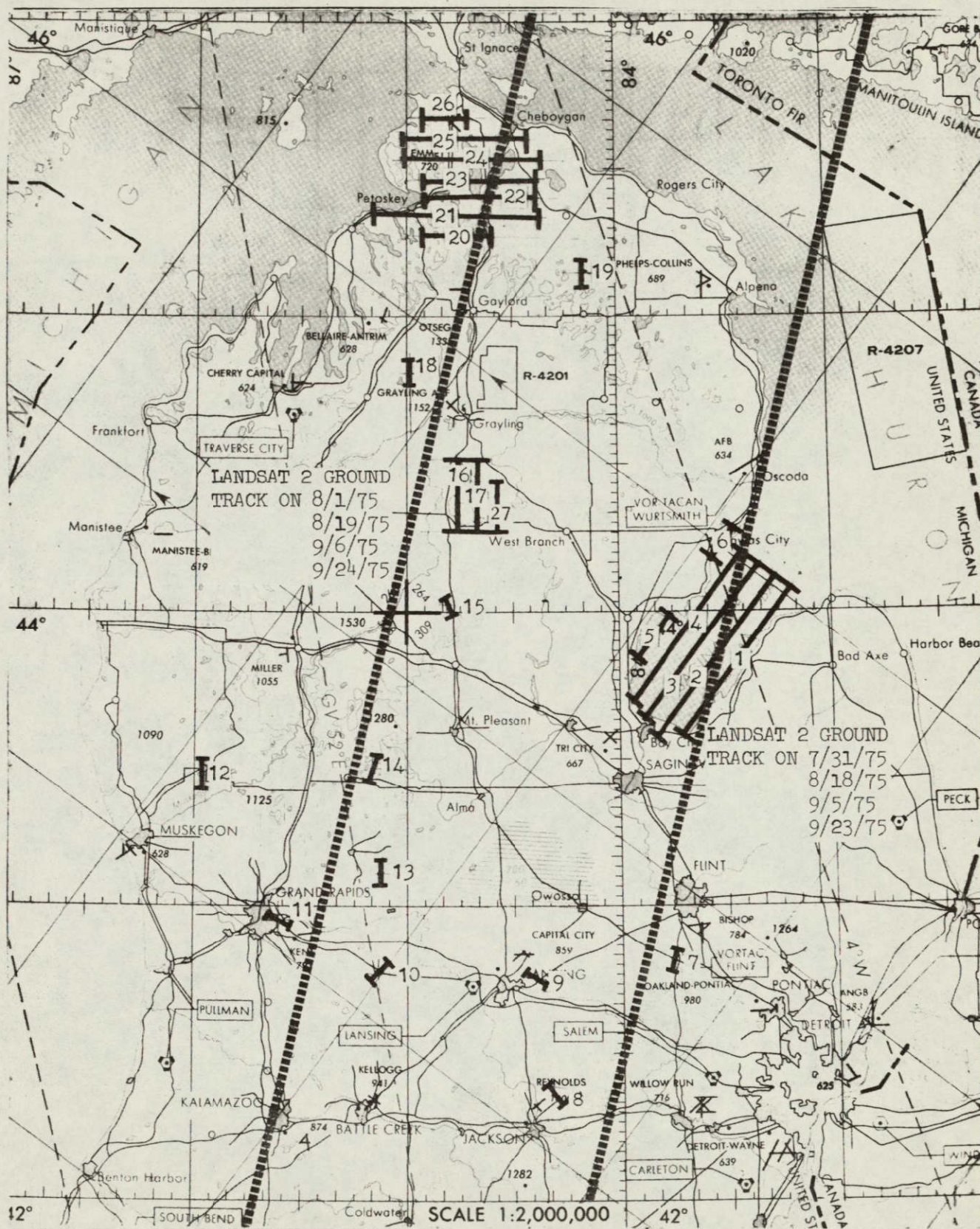


Figure 2. Flight lines for scheduled aircraft coverage of Saginaw Bay and inland test lakes by NASA JSC.

## APPENDIX A

### LAKE EUTROPHIC CATEGORIZATION BY LANDSAT SCANNER DATA

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August 1975  
Special Report

Prepared for:

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15. Supplementary Notes			
16. Abstract <p>By use of distilled water samples in the laboratory, and very clear lakes in the field, a technique has been developed where the atmosphere and surface noise effects on LANDSAT signals from water bodies can be removed. The residual signal dependent only on the material in the water was used as a basis for computer categorization of lakes by type and concentration of suspended material. Several hundred lakes in the Madison and Spooner, Wisconsin area were categorized by computer techniques for tannin or non-tannin waters and for the degree of algae, silt, weeds, and bottom effects present. When the lakes are categorized as having living algae or weeds, their concentration is related to the enrichment of eutrophication of the lake.</p>			
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## Overview

The purpose of this report is to summarize the work done to date on the use of LANDSAT imagery and tapes to classify Wisconsin lakes as to their eutrophic condition. The work covered in this report includes analysis of laboratory reflectance of approximately 20 different lakes as well as analysis of LANDSAT signals of these same lakes. For the laboratory data, the backscatter caused by distilled water was subtracted from that from other water samples. For the LANDSAT imagery the signal from a lake approaching distilled water was subtracted from the signal from the other lakes. The residual signal is a function of only the material in the water. By such a technique it is possible to take out the atmospheric effects and create the characteristic signals from the material in the water. By using such techniques it has been possible to differentiate clear water lakes, tannin water lakes, and lakes with silt and algae in them. Also it is possible to ascertain the concentration of constituents such as algae and to identify where there is a combination of these different constituents in the water.

Imagery and water data from several lakes were closely analyzed to determine just what time for the year would be optimum to classify lakes as to eutrophic condition. Maximum classification potential is found in the latter part of August to the first week of September when there is maximum algal and plant growth. A lake in an enriched status will have a heavy

algal or weed growth at this time while a lake devoid of nutrients will not. Therefore the latter part of August to the first part of September is considered optimum for eutrophic classification.

On the other hand, to determine the differences between pure water and tannin water and to ascertain which lakes have bottom effects showing through it is desirable to make such classifications when the water is the cleanest and the algal growth is at a minimum. This period was found to be mid-May to the first part of June.

Two test classifications have already been run, one for Madison lakes using ERTS imagery of August 18, 1974 and another for Spooner area lakes using an ERTS scene of 12 August 1972. The Madison area lakes all have essentially clear type water with various amounts of algae in them. On the other hand around Spooner Wis. there are these kinds of lakes and also tannin lakes, and lakes where different bottom effects and silt effects occur. To universally use LANDSAT imagery for eutrophic classification it is necessary to handle all these kinds of lakes. Therefore the Spooner area is a necessary site. All these type of lakes occur here while they do not all occur in the Madison area lakes.

These two initial classifications are to be field tested and the second and final classification done in the latter part of summer 1975. A combination of Spring and Summer imagery may be needed to adequately handle the bottom effect problem. The direction of further work here will be determined after a field check is made of the initial classifications.

### Basic Relationships

For using LANDSAT Images for land targets essentially two factors must be understood (1) how the energy interacts with the target and (2) how the signals are effected by the atmosphere. The target can be treated as a diffuse reflector.

For using LANDSAT images for analyzing water targets the situation becomes more complex. Signals originate from

- (1) the particles within the water volume.
- (2) the water surface which behaves partially as a diffuse reflector and partially as a specular reflector.
- (3) from the water bottom where it shows.

All these signals are also modified by the atmosphere.

It is only the signal coming from the water volume which correlates to water quality. Surface, bottom, and atmospheric effects are all noise which must be removed leaving a residual signal which is dependant only on the volume reflectances and therefore the water quality in that volume.

Development of the equations are lengthy and are covered in Appendix A. The important results of this development is that if we subtract the apparent Laboratory Reflectance "AP<sub>1</sub>" for distilled water from the apparent Laboratory Reflectance "AP<sub>2</sub>" of a water sample #2, the Laboratory difference "D<sub>2</sub>", is dependant only on the material in sample #2.

$$D_2 = AP_2 - AP_1$$

Likewise if we take LANDSAT Signals from a clear lake approaching distilled water "W<sub>1</sub>" and subtract this value from the signal from Lake #2, "W<sub>2</sub>", the residual "R<sub>2</sub>" is a signal caused only by the material in lake #2. Surface reflection, foam effects,

and atmospheric effects all are eliminated.

$$R_2 = W_2 - W_1$$

Therefore if we plot  $D_2$  and  $R_2$  versus energy wavelength the curves are essentially the same and vary in magnitude by the factor

$$\frac{R_2}{D_2} = \frac{H_o' \cdot \tau}{\pi \rho_{PL}}$$

Where  $H_o'$  = total outdoor irradiance at water level  
at the instant of the LANDSAT image

$\tau$  = atmospheric transmittance

$\rho_{PL}$  = reflectance of the Laboratory standard  
reflectance panel.

The strength of the signal from the water volume is caused by material in the water. When this material is algae or lake weeds the strength of the signal is related to Eutrophication.

#### Optimum time of year for Eutrophication Classification

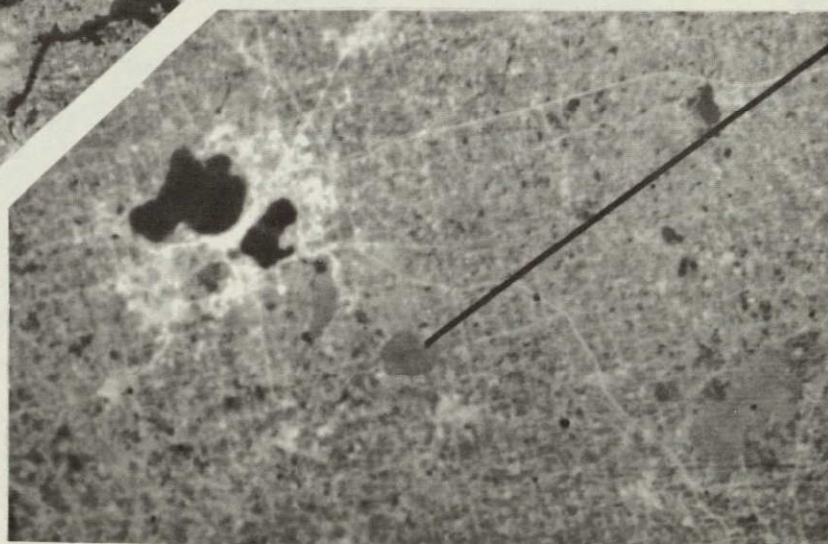
Figures 1, 2 and 3 indicate that the optimum time for Eutrophic Classification is in late August.

APRIL



Devil's Lake (Clear and Oligotrophic)

Lake Kegonsa (Algal and Eutrophic)



LATE AUGUST

FIGURE 1 ERTS (LANDSAT) Images of Lakes near Madison, Wisc. in early Spring when Algae and Lake Weed Growth is a Minimum and in Late August when it is Maximum. Band 5 (Red)

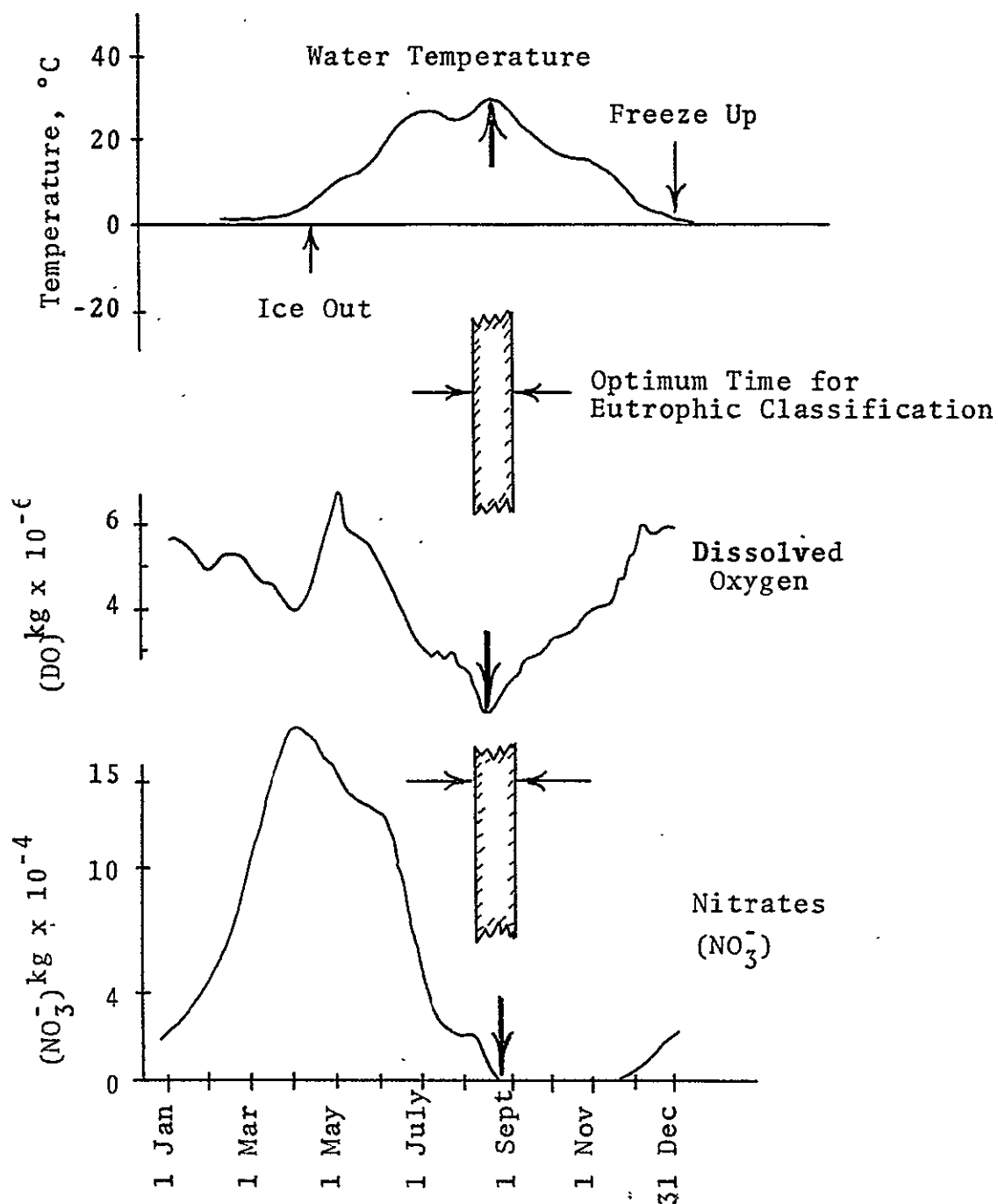


Figure 2 . Water Temperature, Dissolved Oxygen, and Nitrates (Algae Nutrients) Plotted Against Time. Lake Mendota, 1971.

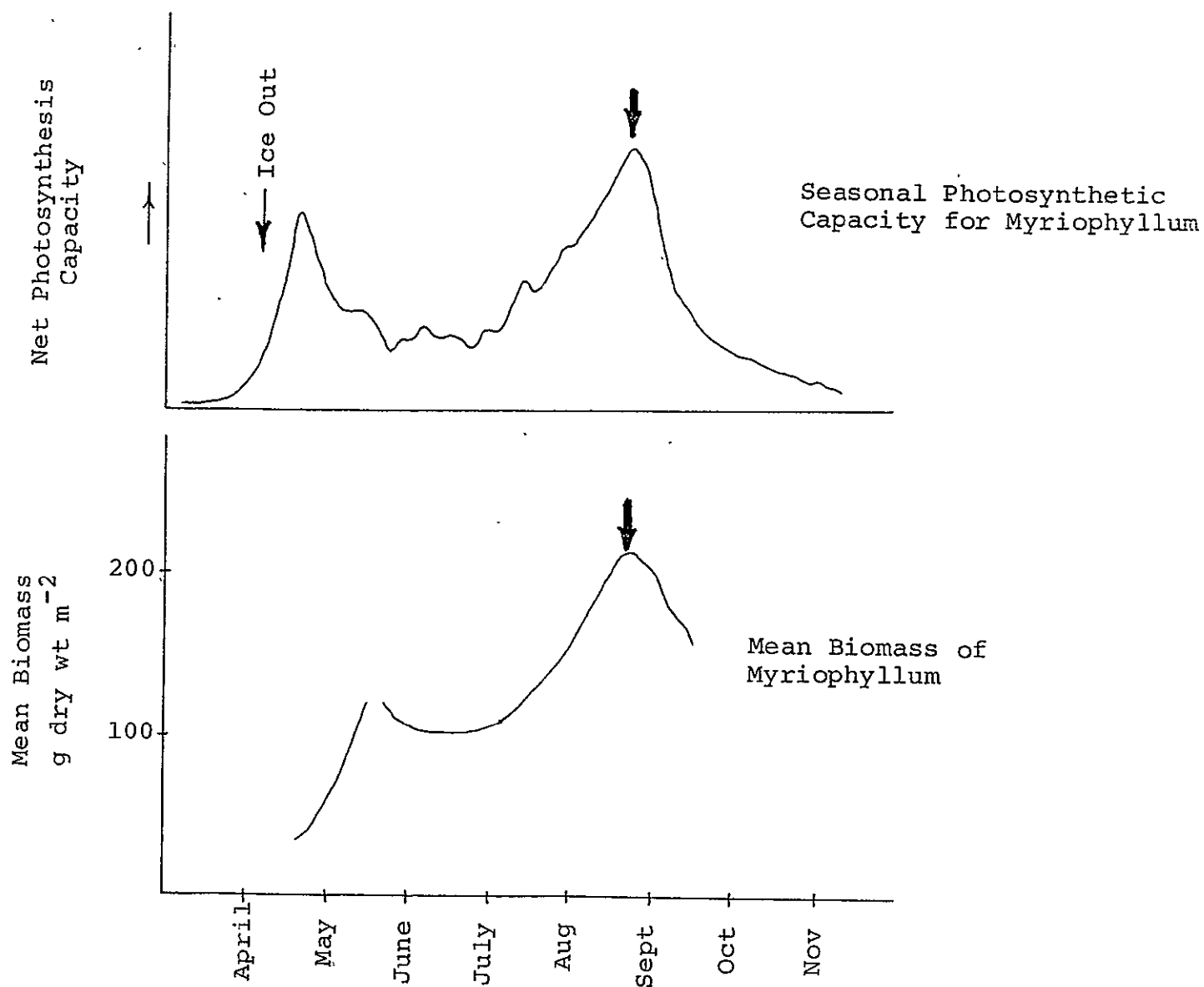


Figure 3. Seasonal Photosynthetic Capacity and Mean Biomass of *Myriophyllum Spicatum* (Rooted Lake Weed) in Lake Wingra (Madison Area Lake) in 1971.

### Laboratory Results

The volume reflectances of material added to pure water is indicative of what that material is and how much is present. The best indication of this material is the difference in apparent reflectances between the water in question and distilled water.

$$D_i = \text{Laboratory Difference} = AP_i - AP_1$$

Figures 4, 5, and 6 show curves of this Laboratory Difference,  $D_i$ , for different types of lakes. These figures show that indeed one can differentiate between tannin and non tannin waters and the types of suspended material in the water by the shapes of the curves. Also the amount of suspended material present is related to the height of the curves. When this suspended material is algae the higher curves are therefore enriched eutrophic lakes.

### Spectral Signatures from LANDSAT Scanners

If one plots the raw signal count from the 4 LANDSAT Scanners versus the middle of the spectral sensitivity of each band, curves as shown in Figure 7 result. The atmospheric effects are very strong especially in Bands 4 and 5 and the total signals are very large. The three curves in Figure 7 are from a clear water lake, a tannin lake and an algal lake.

When the Raw readings from the clear water lake are subtracted from the raw readings from the other lakes the result is the Satellite Residual,  $R_i$ , which varies only from the Laboratory Difference,  $D_i$ , by a constant factor.



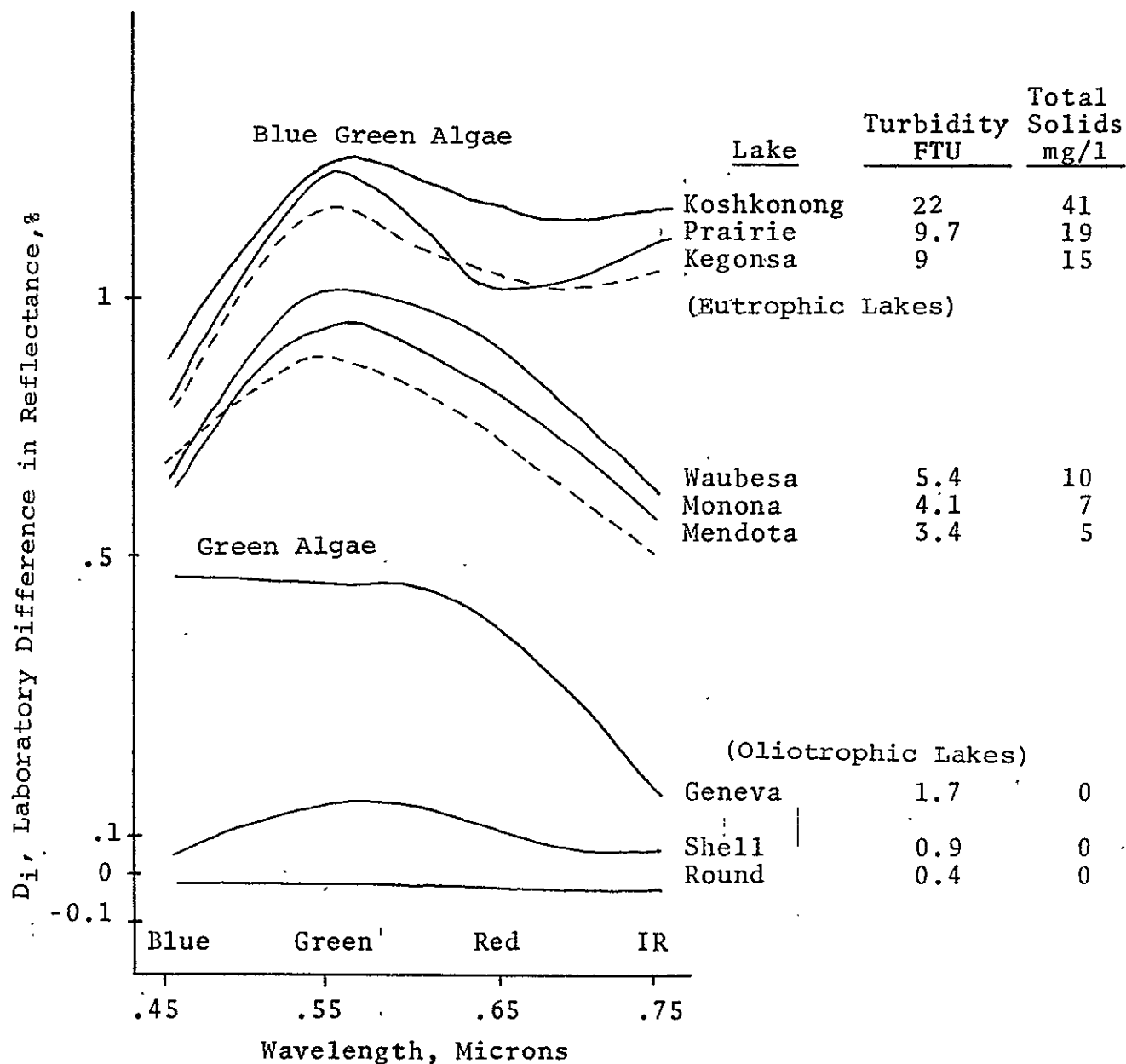


FIGURE 4 - Laboratory Difference in Reflectance Curves,  $D_i$ , for different non-tannin water samples with various amounts of algae.  $D_i$  = Laboratory Apparant Reflectance of Sample minus Reflectance for Distilled water. The more the algae the higher the curve and the eutrophic the lake.

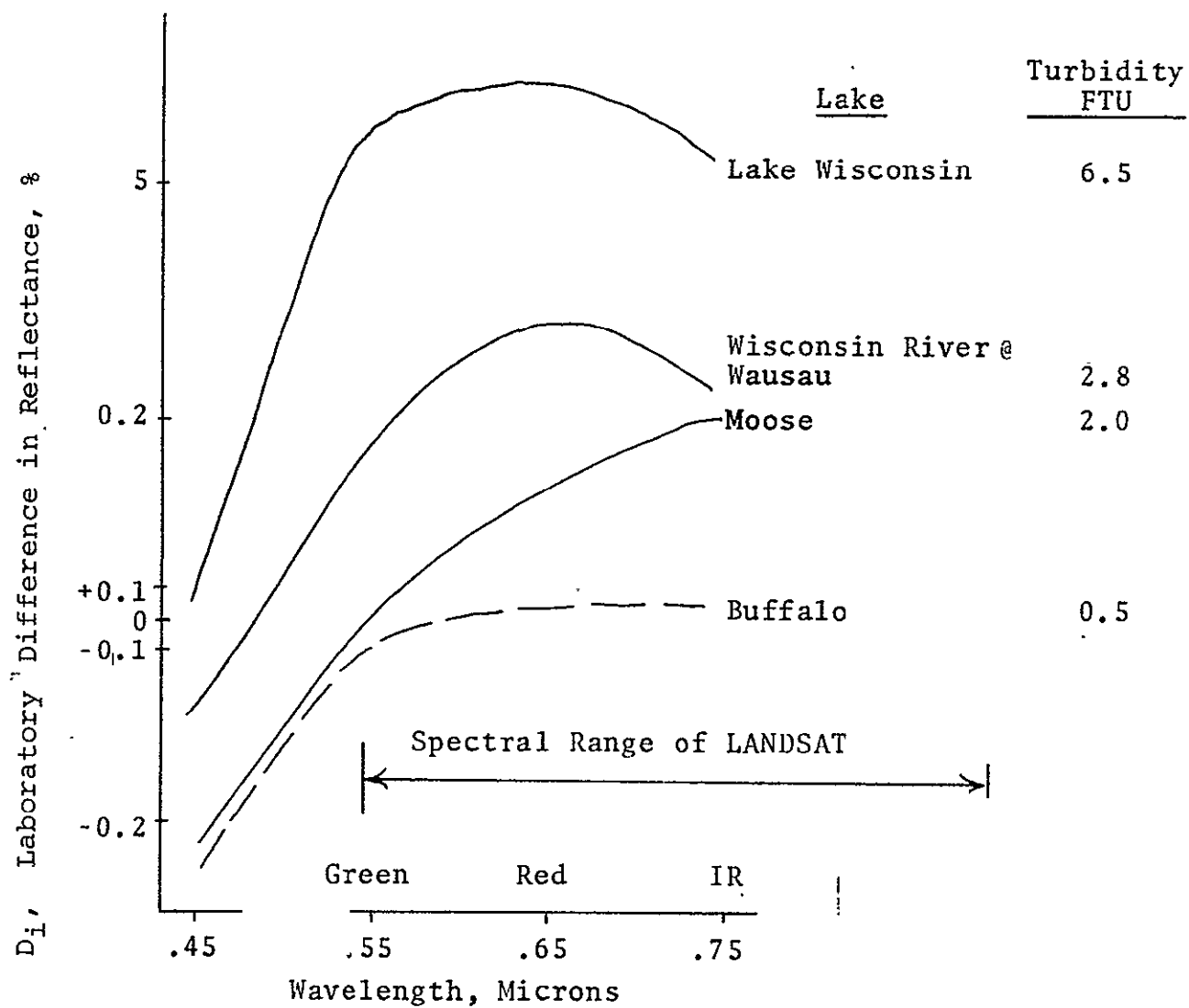


FIGURE 5-Laboratory Difference in Reflectance Curves,  $D_i$ , for tannin type lakes with various amounts of algae present.

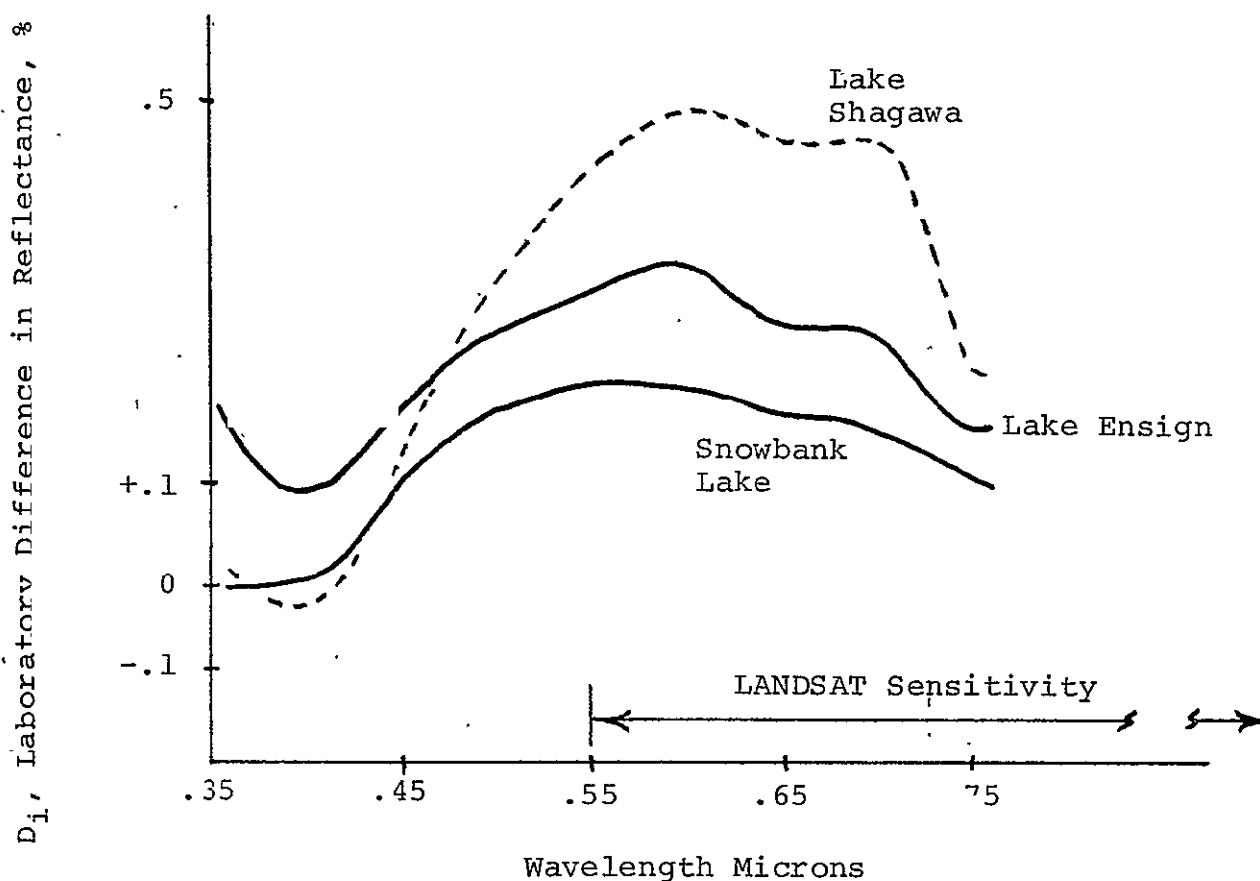


FIGURE 6-Laboratory Difference in Reflectance Curves for three lakes which were classified by the US Forest Service as Eutrophic (Lake Shagawa), as Mesotrophic (Lake Ensign) and as Oligotrophic (Snowbank Lake) Corresponding curves from the LANDSAT scanners are shown on FIGURE 11.

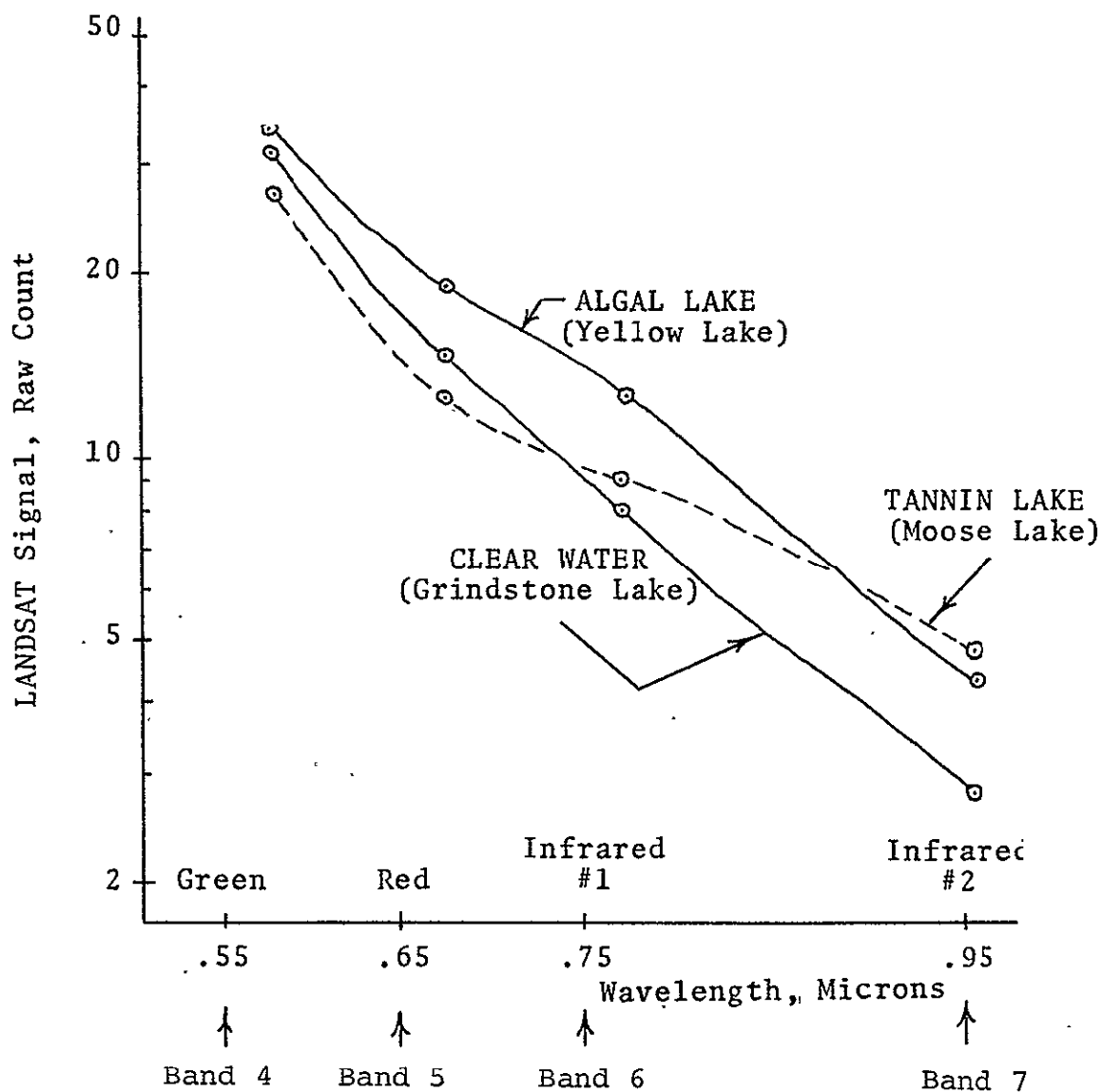


Figure 7 . Satellite Spectral Signatures for three types of Lakes. Raw Count from LANDSAT MultiSpectral Scanners.

Figure 8 shows these Residuals,  $R_i$ , plotted against wavelengths. The shapes of curves for the clear water, tannin water and algal lake are similar to the corresponding laboratory curves shown in Figure 4, 5, and 6.

Not only can the type of water be determined from LANDSAT data alone but also its concentration. Figure 9 shows Satellite Residual curves for non-tannin lakes with various amounts of algae. Figure 10 shows the same for Red Clay in a non-tannin water. Note the unique spectral curves for each water. Figure 11 shows the Satellite Residual Curves for the three lakes in Figure 6 which were classified by the US Forest Service as Oligotrophic, Mesotrophic, and Eutrophic. One can see that the spectral fingerprints are as distinct from the LANDSAT Data in Figure 11 as from the lab Data in Figure 6.

#### Bottom Effects

Bottom Effects are a troublesome noise factor. They can occur in all kinds of waters at various depths and can be caused by various materials such as bright sand, dark mud, green weeds or various combinations of these. Where the bottom signals are strong they can be treated as a unique lake signal and be classified as bottom effects.

Figure 12 shows the effects of a light sand bottom on a relative clear lake. Figure 13 shows the effects of dark mud and wild rice on a tannin lake. Figure 14 shows the effect of lake weeds of various types, at different depths, in a tannin-type lake. The weeds are so thick on this lake that they use all the nutrients and there is no algae. The water is

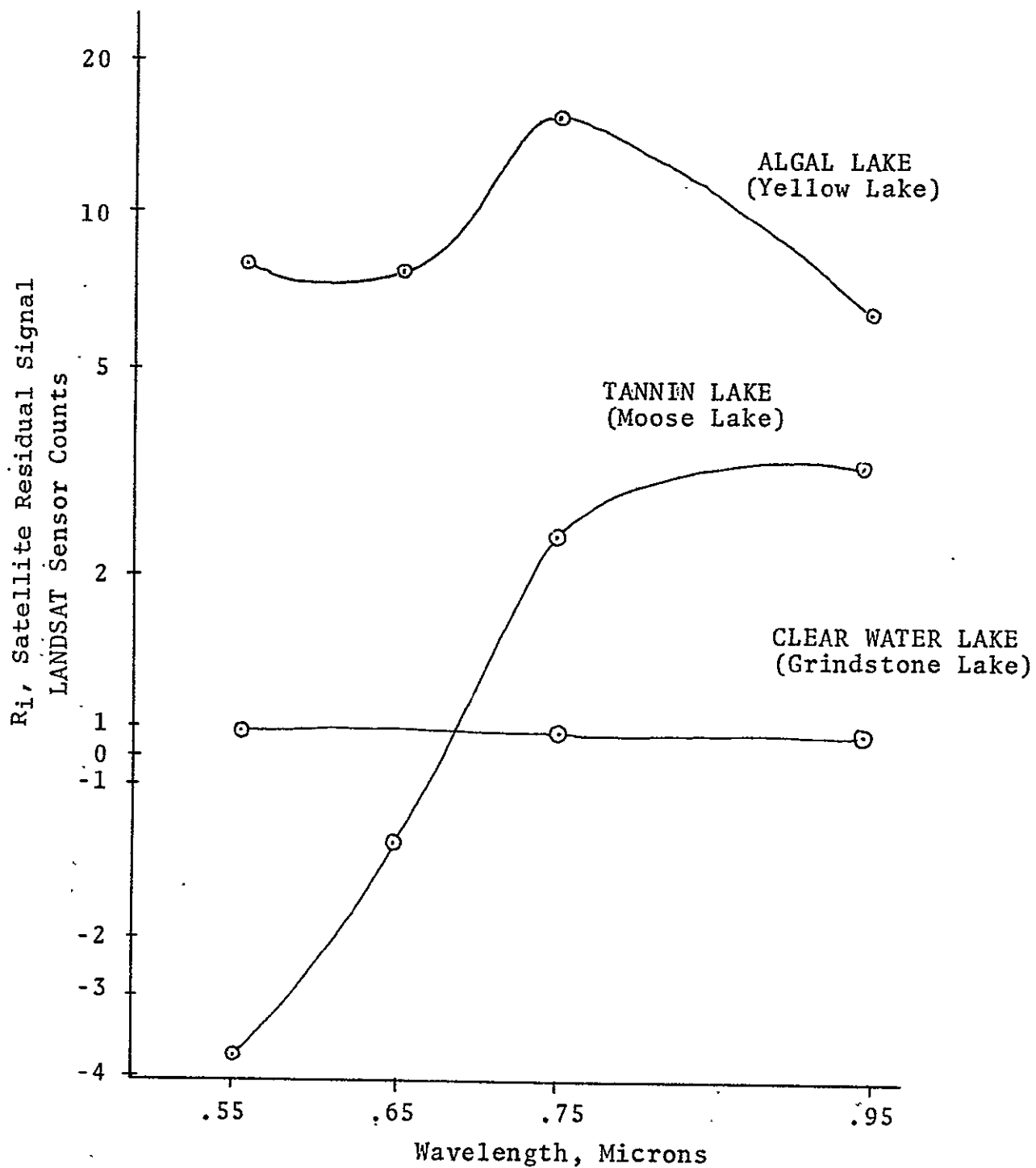


Figure 8. Satellite Residual Spectral Signatures of Three Types of Lakes. The Signal from the Clear Lake has been Subtracted from the Signals from the Other Types Producing Spectral "Fingerprints" Characteristic of Clear Water, Tannin, Algal Type Lakes.

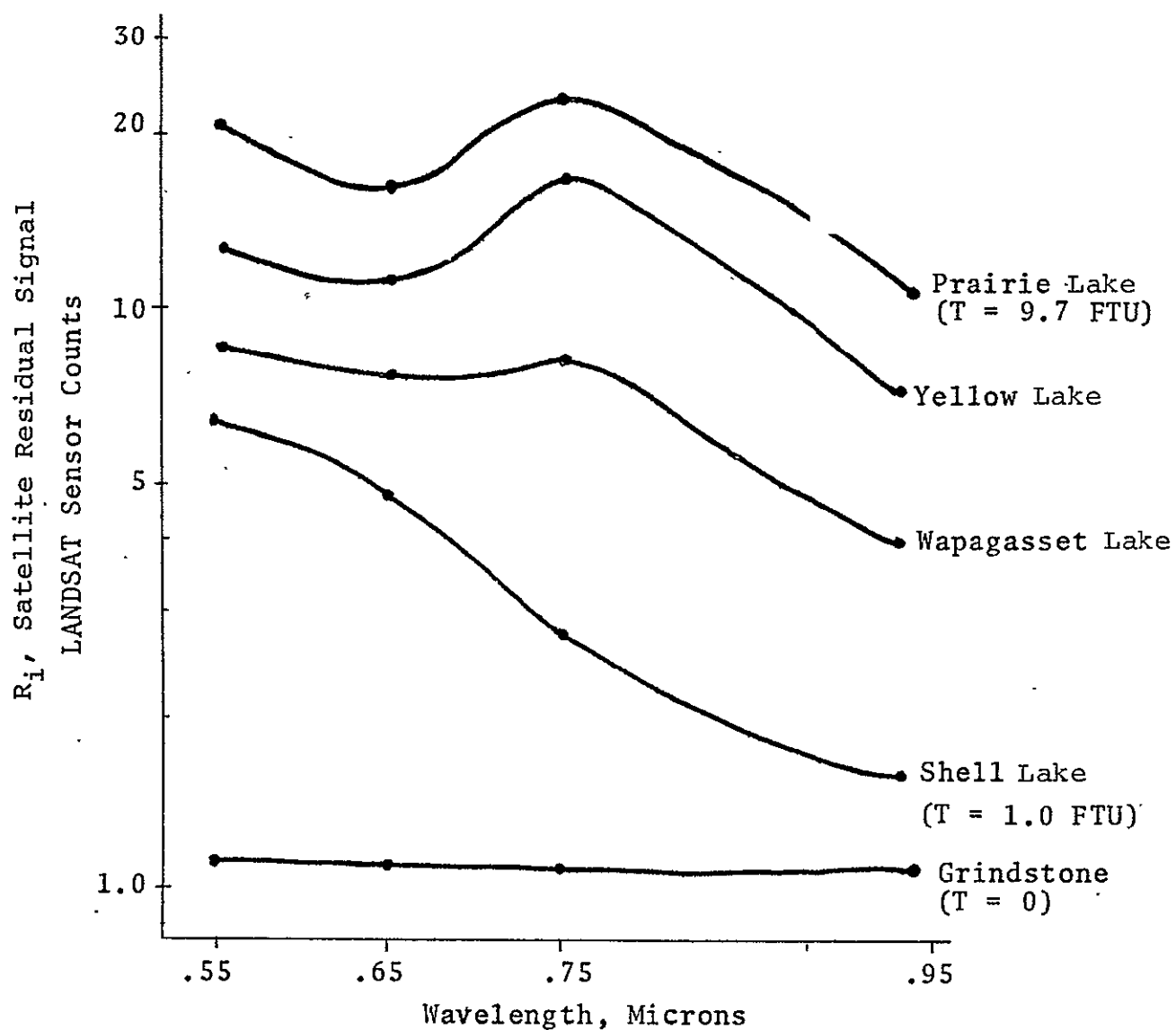


Figure 9 . Satellite Residual Spectral Signatures for Non-Tannin Type Lakes (Clear Water Type) Containing Various Amounts of Algal. (Residual Reflectance = Signal from Target Lake Minus Signal from Very Clear Lake). T = Turbidity

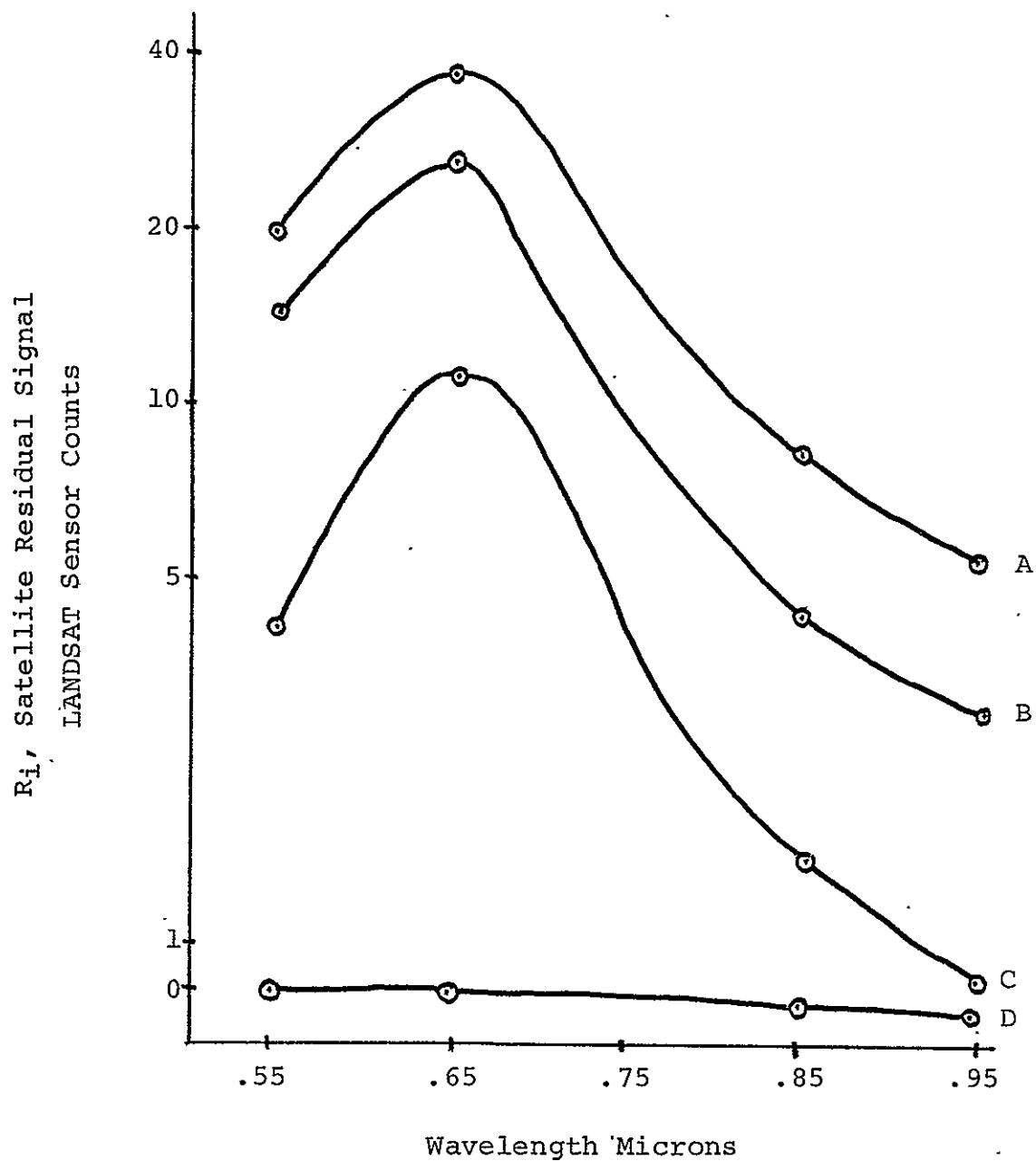


Figure 10 . Effect of Red Clay in Clear Lake Superior Water

Site	Approx. Turb. (ftu)	Approx. Solids (mg/L)
A	100	400
B	50	200
C	5	50
D	0.2	0



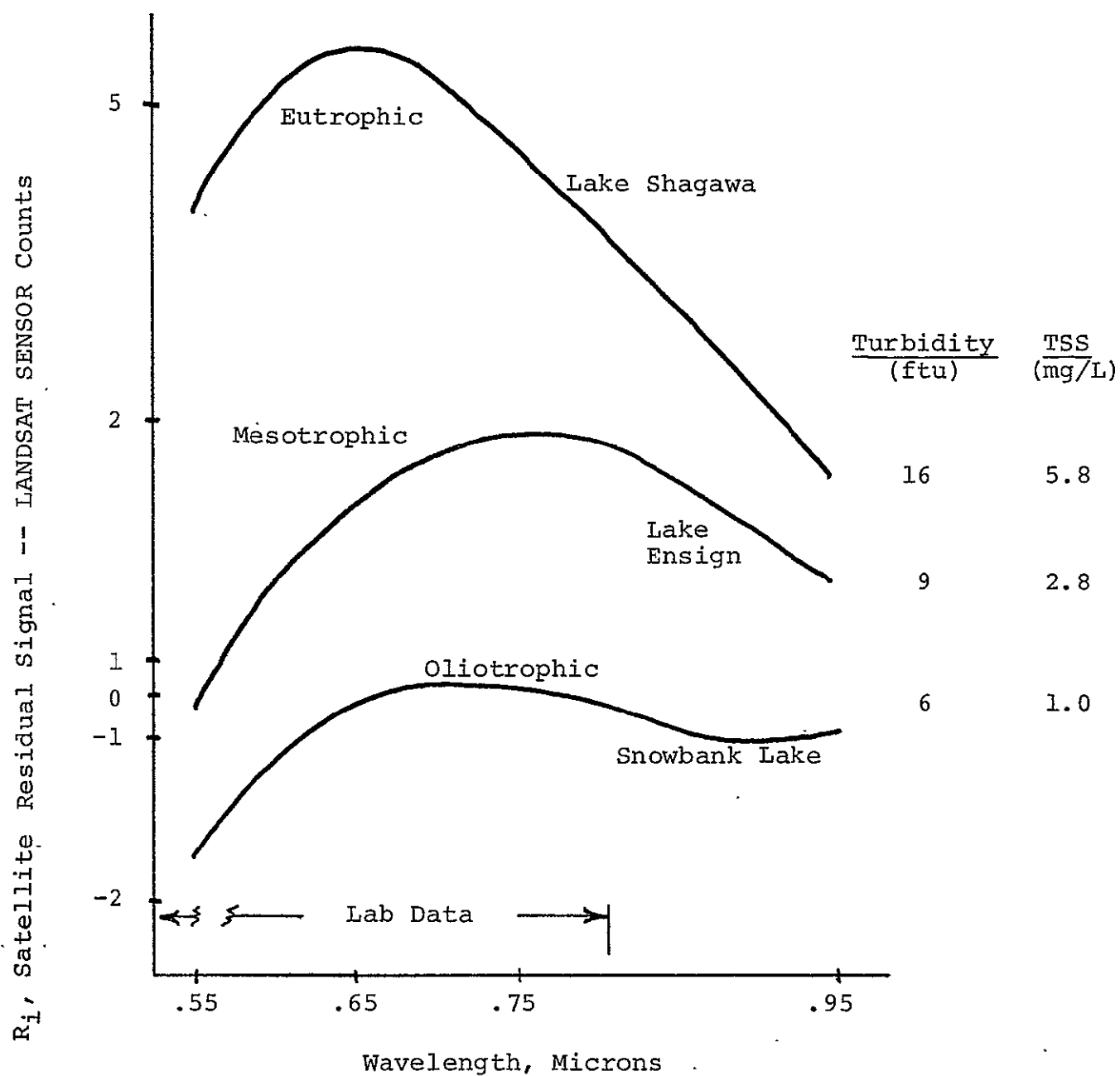


Figure 11. Satellite Signatures from Three Lakes near Ely, Minnesota. Shagawa = Eutrophic, Ensign = Mesotrophic, Snowbank = Oliotrophic.

TSS = Total Suspended Solids

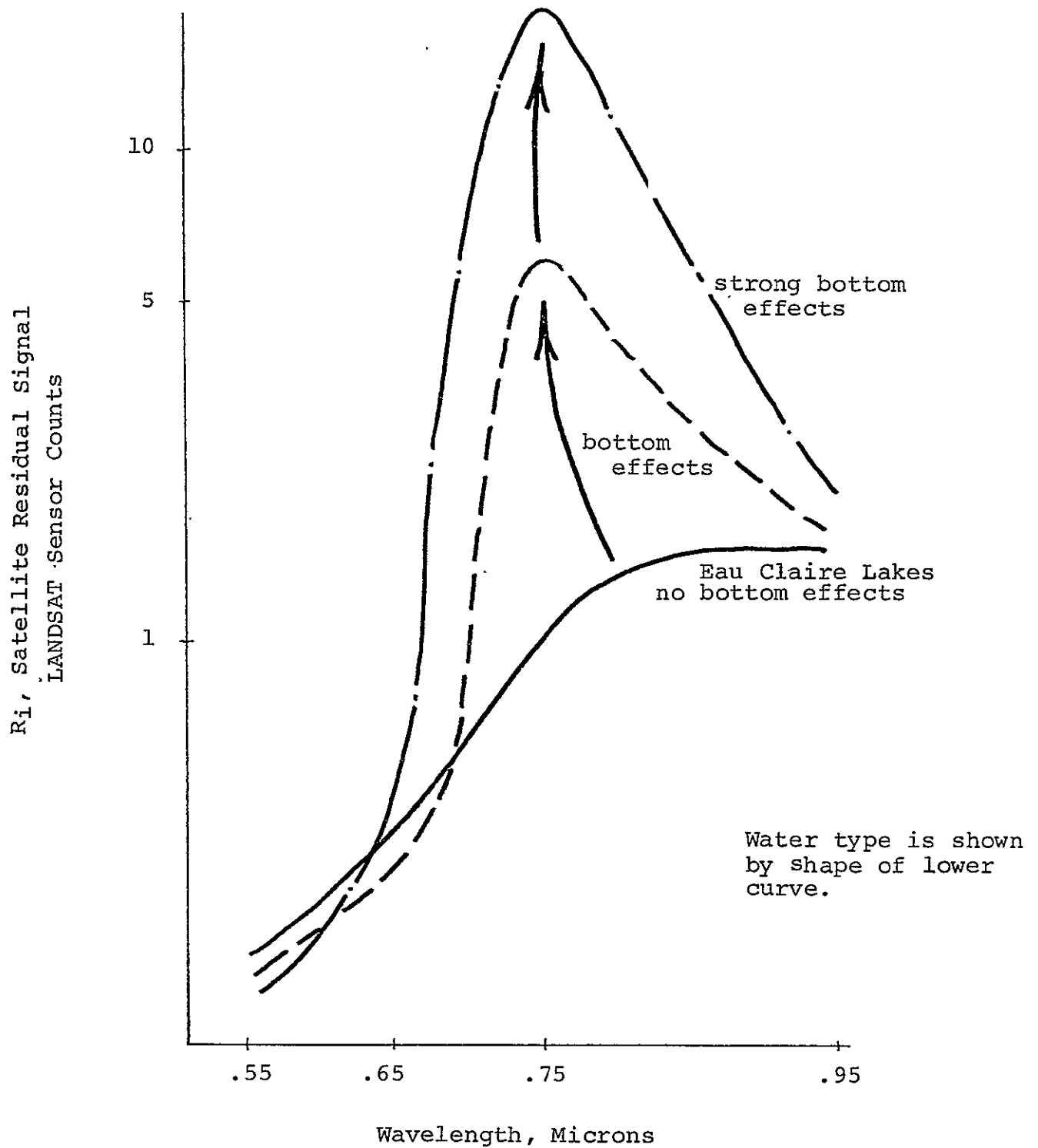


Figure 12. Effects of Sand Bottom on Signal from a Clear Type Lake that has Just a Little Tannin in it.

R<sub>1</sub>, Satellite Residual Signal -- LANDSAT Sensor Counts

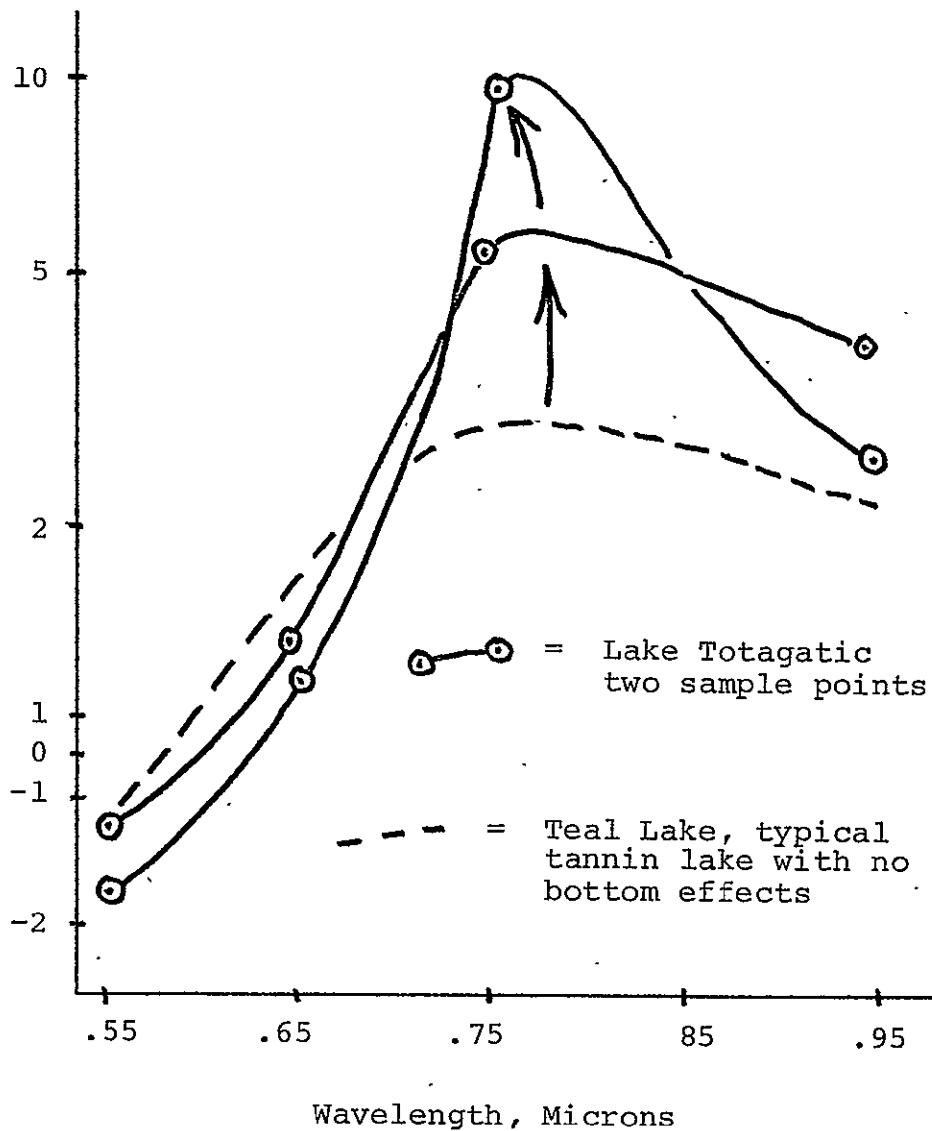


Figure 13. Effects of Mud Bottom and Wild Rice Plants on Satellite Signal from Shallow Tannin Lake "Where Bottom is Visible over Entire Lake".

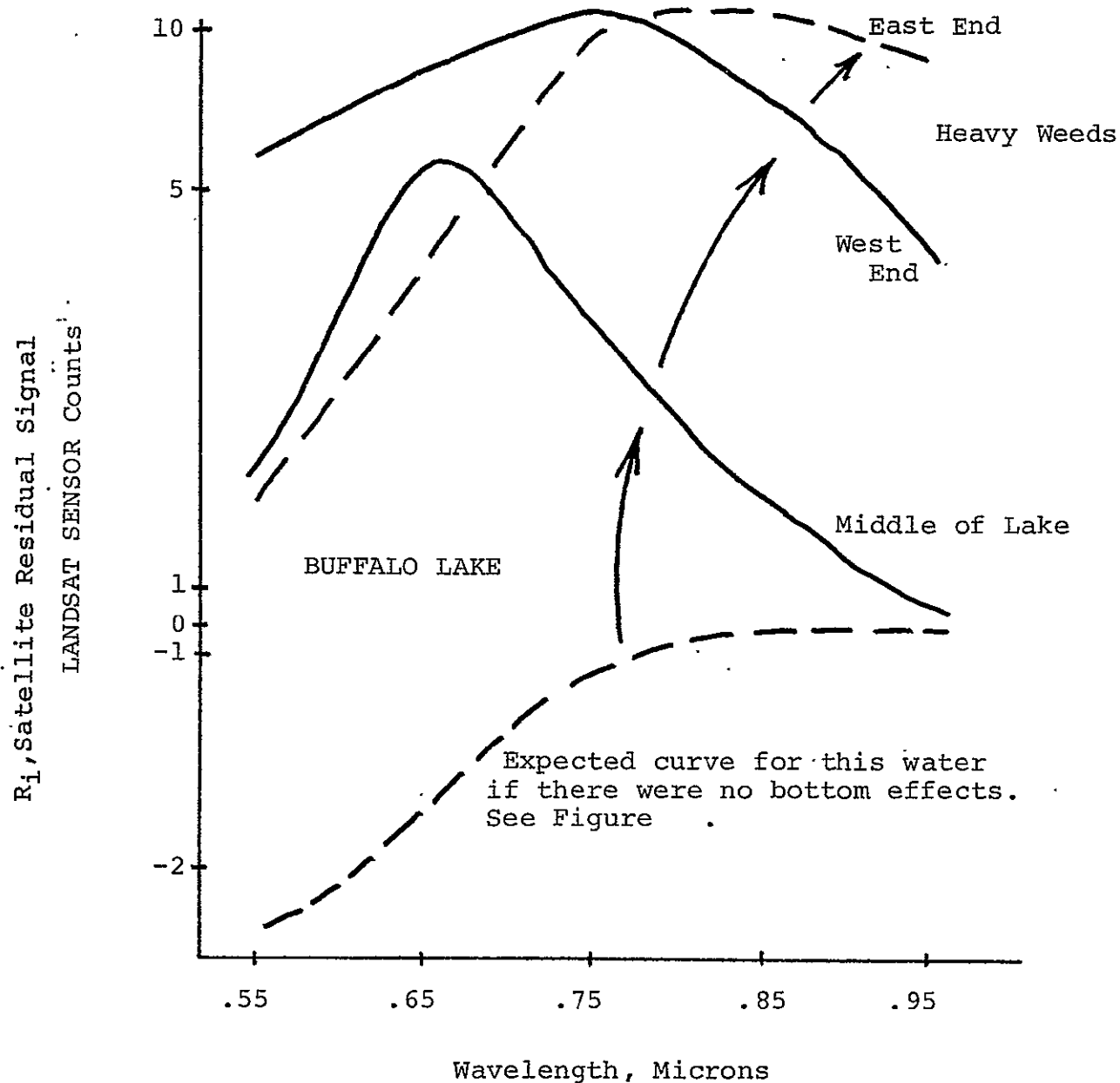


Figure 14. Effect of Shallow Mud Bottom and Heavy Weed Growth on the Expected Signal from a Non-Turbid Tannin Lake. (Although the water is low in turbidity ( $T = 0.5$ , Figure 5) and free of algae, this is an eutrophic type lake because the nutrients are tied up in the lake weeds.)

as clear as from a Oligotrophic lake (Figure 5) yet the weeds make it very much Eutrophic. In such cases the bottom weed signals are a very important indicator of Eutrophic Class. Figure 15 shows bottom effects in a different lake caused by different types weeds.

Where the bottom effects are strong, although varied, they can be treated as a unique signal and can be identified as bottom effects. However where the bottom effects are dark mud in dark tannin lakes they are easily confused with other tannin lakes with no bottom effects. Figure 16 shows the range of signals from typical tannin lakes with no bottom effects. Figure 17 shows the curve for St. Croix Flowage which is a shallow lake with many weeds and would probably be classified as Eutrophic. However the dark mud showing through depresses the curve to be similar to a tannin lake with no bottom effects nor weeds nor algae.

It is anticipated that lakes with bottom effects can be adequately identified by analyzing LANDSAT data analysis from the spring when the water is clearest and when there is no algae nor weeds. Figure 18 shows that the optimum time for such data is the last two weeks of May.

It is anticipated that data from May 1975 will soon be analyzed and possibly combined with August data to adequately handle the bottom effect problem. In the meantime LANDSAT data from two days have been analyzed by M-DAS and color categorized tapes produced. Figure 19 and 20 shows maps of the areas analyzed. Figure 21 shows a sample of the results.

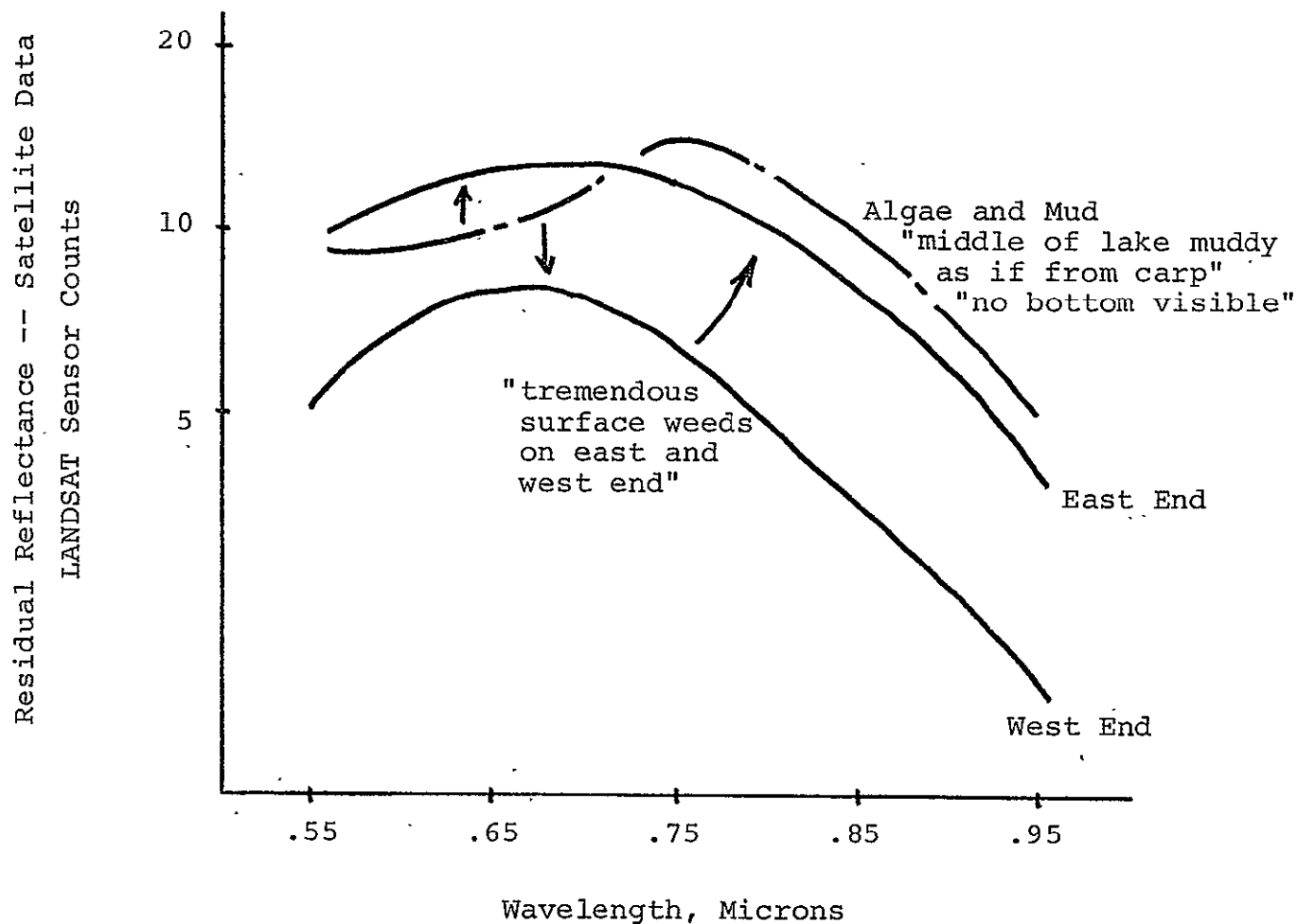


Figure 15. Effect of Dense Surface Weed Growths on a Muddy Algal Lake, Lake Puckaway. The "ground truth" here is aerial observations from a small plane.

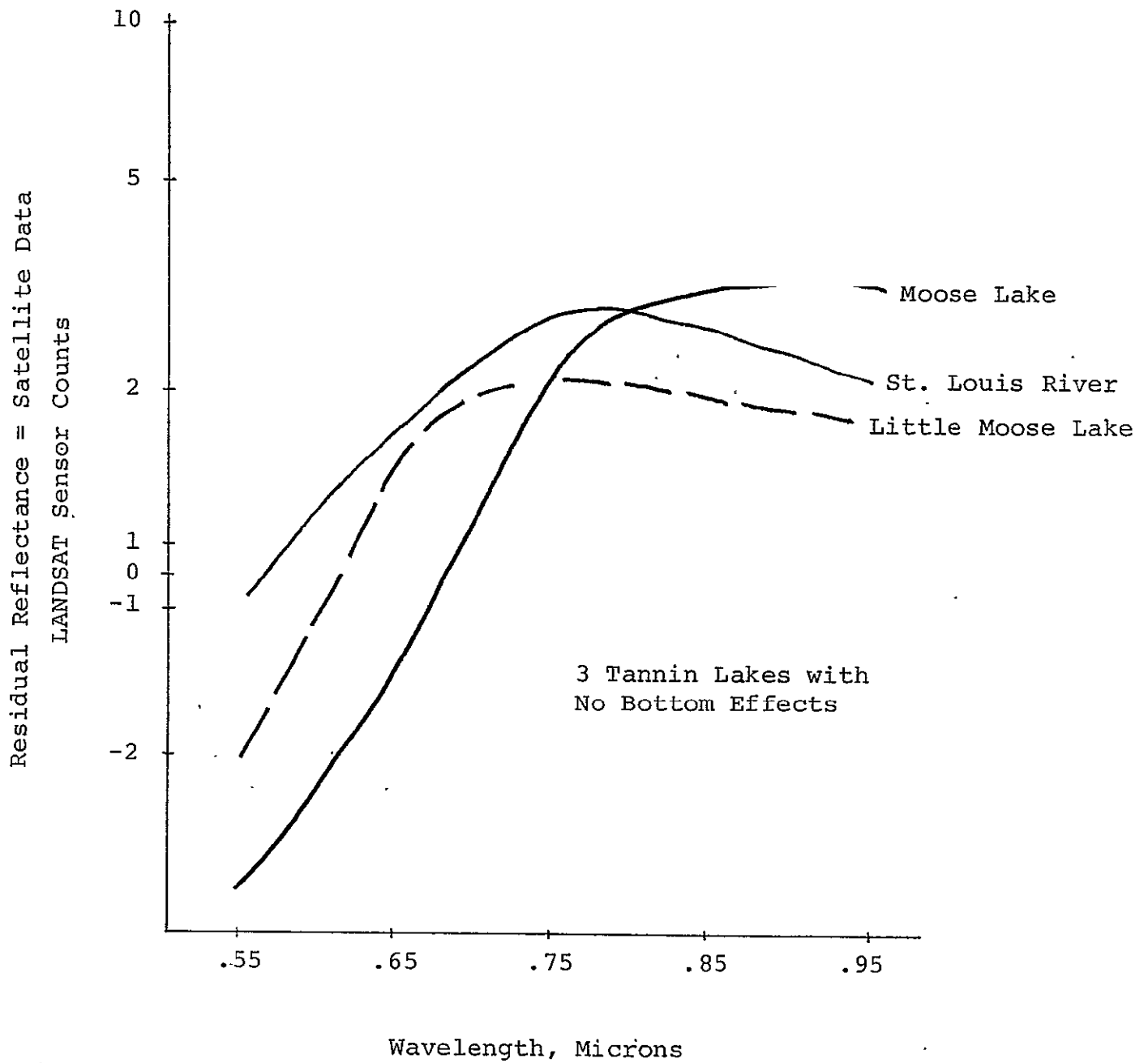


Figure 16. Several Tannin Type Lake Signatures.  
From LANDSAT data.

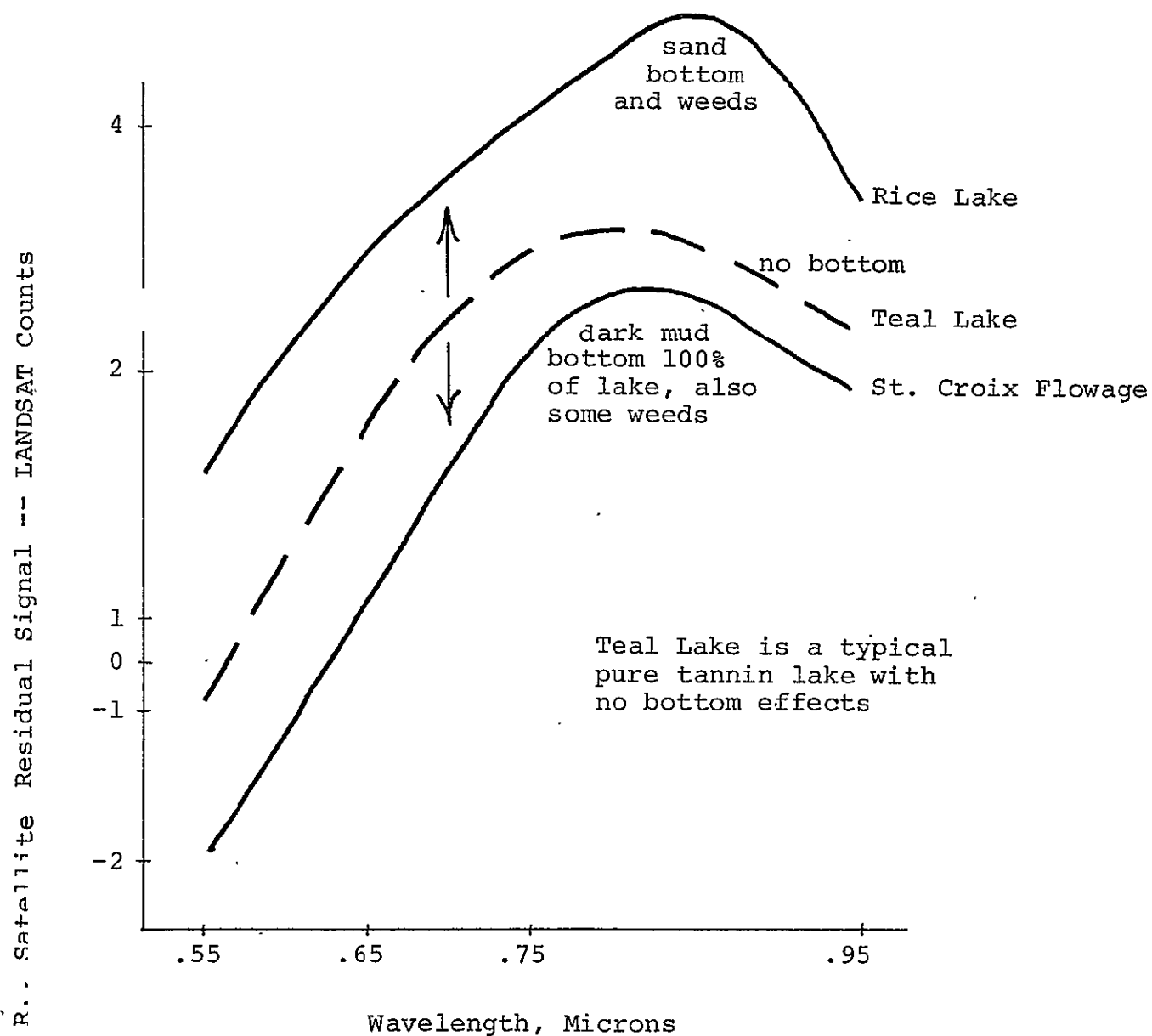


Figure 17. Satellite Signature for 3 Tannin Lakes, Showing How the Signal Can be Shifted either Up or Down Depending on the Type of Bottom. Mild bottom effects for such lakes appear to be no discernable by spectral signatures alone.



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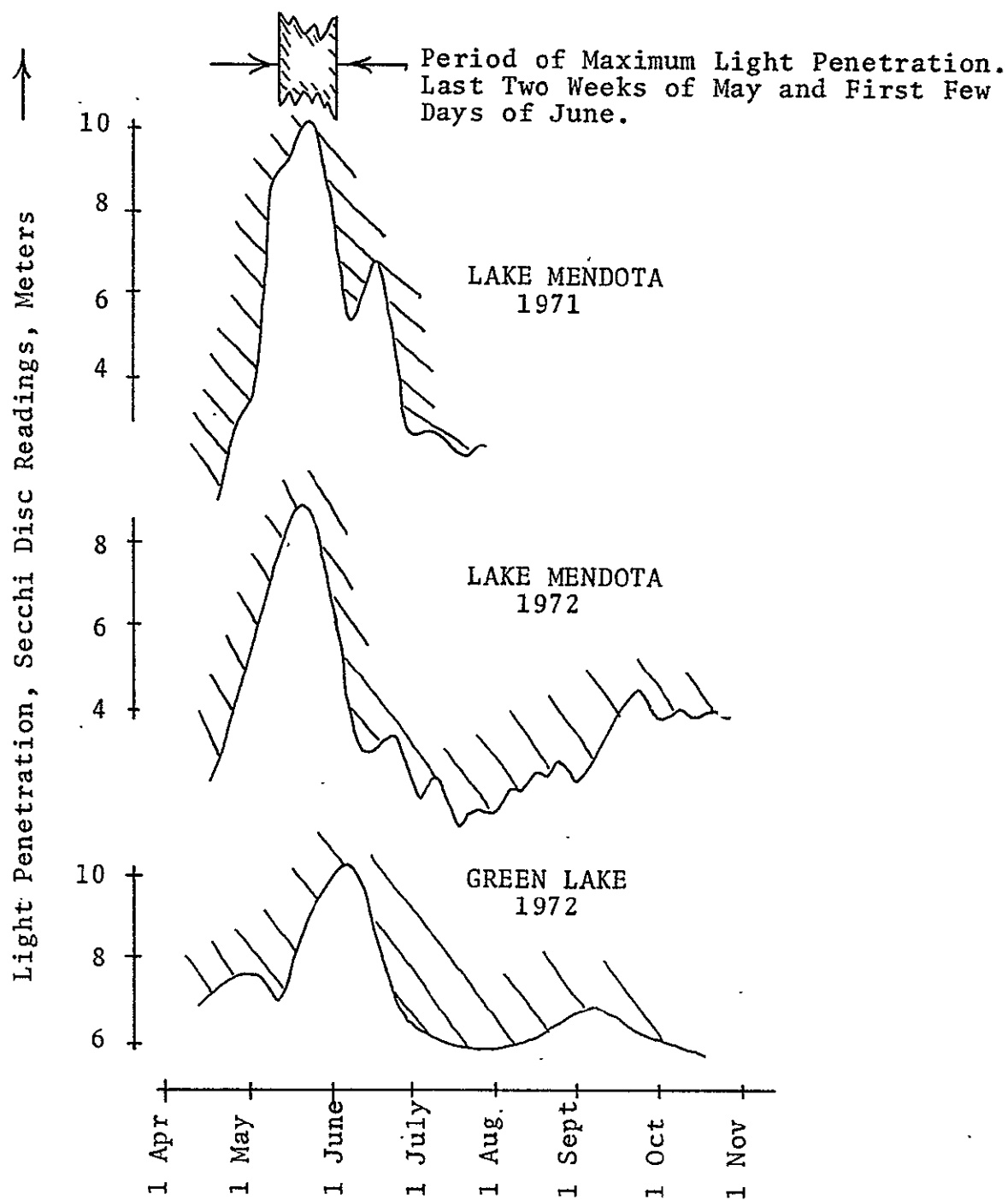


Figure 18. Plot of Light Penetration (Secchi Disc Reading) Versus Time.

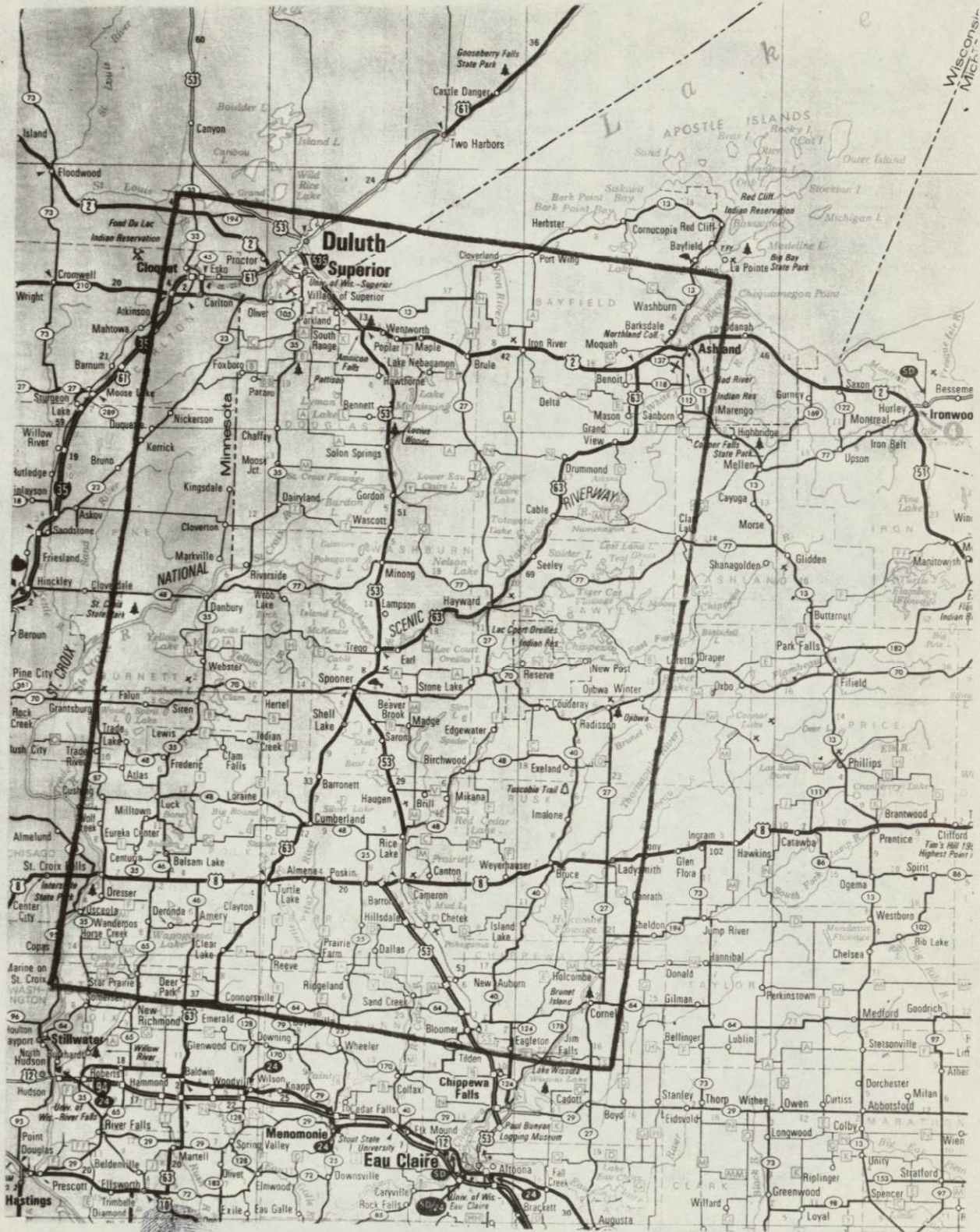


FIGURE 19 Map showing Part of Aug 12 Scene  
Converted to Color Catagorized tape  
By the Bendix M-DAS System.  
Spooner Area Lakes



ORIGINAL PAGE IS  
OF POOR QUALITY



FIGURE 20 Map Showing Area of August 18, 1974 Scene  
Converted to Color Categorized Image  
By The Bendix M-DAS System



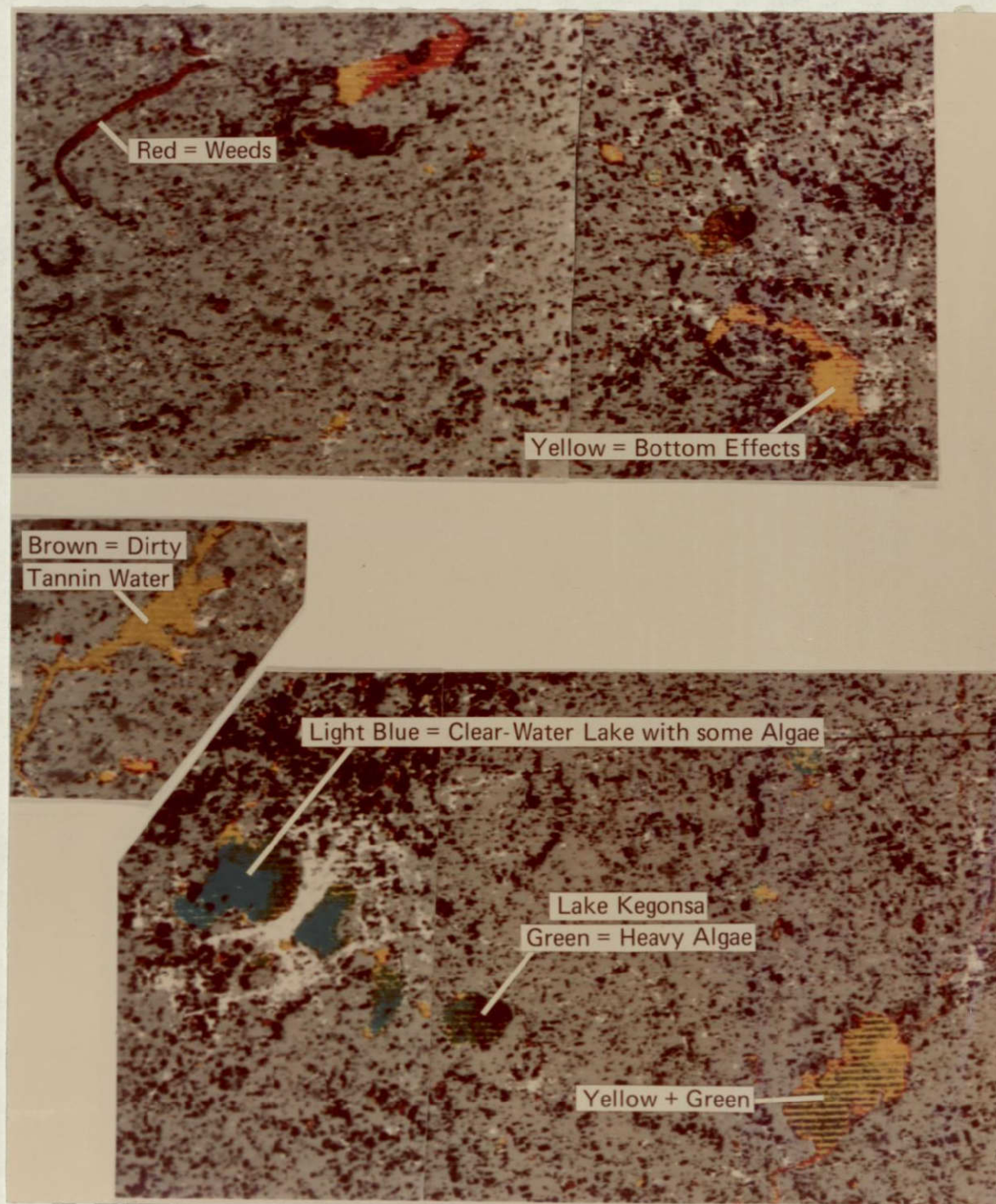


Figure 21 Initial Color Categorized Image Produced by Bendix Corp. Showing Lake Categorization. (LANDSAT Scene 1756-16061 of 18 August 1974)

The initial results look good and are being field tested in late Summer 1975. Spring data will be combined with the results of the August 1975 field effort and the final categorization will be made toward Spring 1976.